City of Riverside

WASTEWATER COLLECTION AND TREATMENT FACILITIES INTEGRATED MASTER PLAN

VOLUME 4: WASTEWATER TREATMENT SYSTEM
CHAPTER 9: DISINFECTION

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City of Riverside

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VOLUME 4: WASTEWATER TREATMENT SYSTEM
CHAPTER 9: DISINFECTION

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Chapter 9

DISINFECTION

9.1 PURPOSE

The purpose of this chapter is to evaluate expansion alternatives for the City of Riverside (City) Regional Water Quality Control Plant (RWQCP) disinfection system that will meet California Title 22 standards. Ultraviolet (UV) and/or ozone disinfection are compared with the existing sodium hypochlorite (NaOCl) chlorination and dechlorination system.

9.2 CONCLUSIONS AND RECOMMENDATIONS

- Existing NaOCl should continue to be used as the disinfection method unless future regulations require removal of pollutants that only advanced disinfection systems can provide.
- Ozone or ozone plus UV should be considered for disinfection if removal of Endocrine Disrupting Compounds (EDCs) is required by future regulations. These alternatives will be developed as alternate treatment scenarios for the Master Plan Manager™ (MPM™).
- UV alone will not be used as the disinfection method because it is incapable of removing EDCs.
- A tracer test should be performed for each existing chlorine contact basin in order to determine the size requirement for new basins.

9.3 DESIGN CRITERIA

The average and maximum daily flows to the disinfection facilities are 52 mgd and 78 mgd, respectively.

California Title 22 standards are used for the evaluation in this Chapter. Title 22 requires disinfected tertiary recycled water to meet the following criteria:

1. The filtered wastewater has been disinfected by either:
    a. A chlorine disinfection process following filtration that provides a CT (the product of total chlorine residual and modal contact time measured at the same point) value of not less than 450 milligram-minutes per liter at all times with a modal contact time of at least 90 minutes, based on peak dry weather design flow; or
    b. A disinfection process that, when combined with the filtration process, has been demonstrated to inactivate and/or remove 99.999 percent of the plaque-forming units of F-specific bacteriophage MS2, or polio virus in the wastewater. A virus that is at least as resistant to disinfection as polio virus may be used for purposes of the demonstration.

2. The median concentration of total coliform bacteria measured in the disinfected effluent does not exceed an MPN of 2.2 per 100 milliliters utilizing the bacteriological results of the last 7 days for which analyses have been completed and the number of total coliform bacteria does not exceed an MPN of 23 per 100 milliliters in more than one sample in any 30-day period. No sample shall exceed an MPN of 240 total coliform bacteria per 100 milliliters.

For the Integrated Master Plan, the dose and contact time of each disinfection alternative to meet the above requirements are listed in Table 9.1.

Table 9.1 Design Criteria for Disinfection Alternatives
Wastewater Collection and Treatment Facilities Integrated Master Plan
City of Riverside

Disinfection	Dose	Contact Time
NaOCl	450 mg-min/L	106 min[1]
UV[2]	100/80 mJ/cm^2[3]	-
Ozone[4]	5 mg/L	15 min
Ozone and UV[5]	Ozone: 3 mg/L	-
	UV: 100/80 mJ/cm^2[3]	

Notes:
(1) Modal contact time equals 90 minutes, based on an assumed ratio of modal contact time to theoretical contact time of 0.85.
(2) UV as the only disinfection method, using open-channel reactors.
(3) Dose for tertiary filtrate/membrane bioreactor (MBR) effluent. Total dose includes fouling and aging factors.
(4) Ozone as the only disinfection method, using contact basins for MBR effluent only.
(5) Ozone in-pipe contactor followed by in-vessel UV reactor. Without published studies quantifying the disinfection credit of ozone pretreatment, the UV dose is assumed the same as without ozone pretreatment. This could be lowered upon pilot testing.

9.4 EXISTING DISINFECTION FACILITIES

The existing disinfection facilities are listed in Table 9.2. As discussed in Volume 4, Chapter 1 - Existing Facilities, the RWQCP has three Chlorine Contact Basins (CCBs) for chlorination. Water from CCB1 discharges into CCB2 or CCB3. CCB2 is currently out of service. Part of the CCB1 effluent is used as recycled water for the Van Buren Golf Course and RWQCP utility water needs. The remaining portion of the CCB1 effluent goes through CCB3 for either urban forest irrigation or river discharge. Sodium bisulfite is used to dechlorinate the flow that is discharged to the river.

Table 9.2 Existing Disinfection Facilities
Wastewater Collection and Treatment Facilities Integrated Master Plan
City of Riverside

Description	Value		
Chlorination			
Disinfection Chemical	Sodium Hypochlorite (NaOCl)		
Current Chemical Dose	5 to 8 mg/L		
Chlorine Contact Basins	CCB 1	CCB 2	CCB 3
Length to Width Ratio	18.5:1	63.5:1	48:1
Volume	448,320 gal	1,426,470 gal	3,022,960 gal
Total Volume	4.90 MG		
Theoretical Contact Time	106 min		
Modal Contact Time	90 min		
Existing Capacity	44 mgd (Average Daily Flow)		
Dechlorination			
Dechlorination Chemical	Sodium Bisulfite ($NaHSO_3$)		

To evaluate the capacity of the existing CCBs, a modal contact time of 90 minutes is used to meet Title 22 standards. Ideally, water entering a basin will travel from the inlet to the outlet for a period equal to the reactor volume divided by the flow rate, which is termed as theoretical contact time. However, because of back-mixing and velocity currents, along with short-circuiting and dead zones, the modal contact time is shorter than the theoretical contact time. The modal contact time corresponds to the maximum concentration in a tracer curve for a pulse-input tracer test.

Because no tracer tests have been performed on the three CCBs, the ratio of modal contact time to the theoretical contact time is assumed to be 0.85 to calculate the maximum basin capacity. Applying a tertiary peaking factor of 1.5, the current disinfection capacity is 44 mgd on an average daily basis. An additional facility with a capacity of 8 mgd is needed for expansion to 52 mgd. If tracer tests are performed for the three CCBs and the results show that the modal contact time is close to the theoretical contact time for all CCBs, then a small capacity may be needed. Also, it may be possible to modify the basins to improve modal contact time. Therefore, it is recommended that the City perform tracer tests on each of the existing CCBs.

The chemical systems for chlorination and dechlorination, including the feed equipment and chlorine storage facilities, will be evaluated as needed for the 52-mgd expansion during preliminary design.

9.5 EXPANSION ALTERNATIVES

Increased understanding of chlorine-based disinfection shortcomings on pathogens and rising public and regulatory concerns on Disinfection By-Products (DBPs) such as Trihalomethanes (THMs) and Haloacetic Acids (HAA5), have pushed the wastewater treatment industry to look for alternative disinfectants to chlorine. Advances in analytical methods coupled with toxicity research on humans and wildlife may result in the regulation of constituents that are not currently regulated at wastewater treatment plants. These constituents may include nitrosamines, (e.g., N-nitrosodimethylamine (NDMA), N-nitrosodiethylamine (NDEA), N-nitrosodi-n-propylamine (NDPA)), and EDCs.

For the Master Plan, UV and ozone are considered as alternatives to the existing hypochlorite disinfection. UV disinfection is considered because it is a well-proven and cost-effective disinfection technology. Ozone is a much less common wastewater treatment technology than UV, and it is currently not accepted by the California Department of Health Services (CDHS) as an approved technology for the production of recycled water. However, there are several full-scale ozone installations for water treatment disinfection. In addition, there are studies that suggest that ozone is an effective disinfectant with a strong potential for EDC destruction.

9.5.1 Sodium Hypochlorite

While chlorine-based disinfection is predicted to be phased out gradually, it is likely to maintain some presence until other treatment methods capable of leaving a measurable disinfection residual are developed. For recycle and reuse, even with advanced disinfection such as ozone and UV, a 2-mg/L chlorine residual is recommended in distribution systems to control bacterial regrowth. The advantages and disadvantages of NaOCl disinfection are as follows:

9.5.1.1 Advantages

- Existing disinfectant at the RWQCP, so operating experience exists.
- Most economical.
- Provides disinfection residual for recycled water.

9.5.1.2 Disadvantages

- Disinfection by-product formation.
- Risk of transporting and storing a hazardous chemical.
- Potential lower capability of virus and protozoa removal when compared to ozone and UV.
- Higher Total Dissolved Solids (TDS) in the effluent.
- Requires dechlorination for river discharge.

9.5.2 Ultraviolet

UV disinfection is a well-proven and robust process when the reactor design is optimized and particles do not shield pathogens or interfere with light transmission. A low-pressure high-intensity UV channel is shown on Figure 9.1. UV radiation at a wavelength of 254 nm is an effective agent to inactivate microorganisms by damaging their DNA. The inactivation of microorganisms is proportional to the intensity multiplied by the time of exposure to UV, termed as UV dose. The actual UV dose reaching the microorganism depends on factors such as the UV transmittance (UVT), flow rate, the geometry of the UV reactor, and the hydraulics of the system. The advantages and disadvantages of UV disinfection are as follows:

9.5.2.1 <u>Advantages</u>

- Physical process: No disinfection by-products.
- Higher virus and protozoan pathogen inactivation than chlorine-based disinfection.
- Fast reaction time and small footprint.
- Compatible with chlorination to provide a multiple barrier. Pre-UV chlorination provides algal growth control.

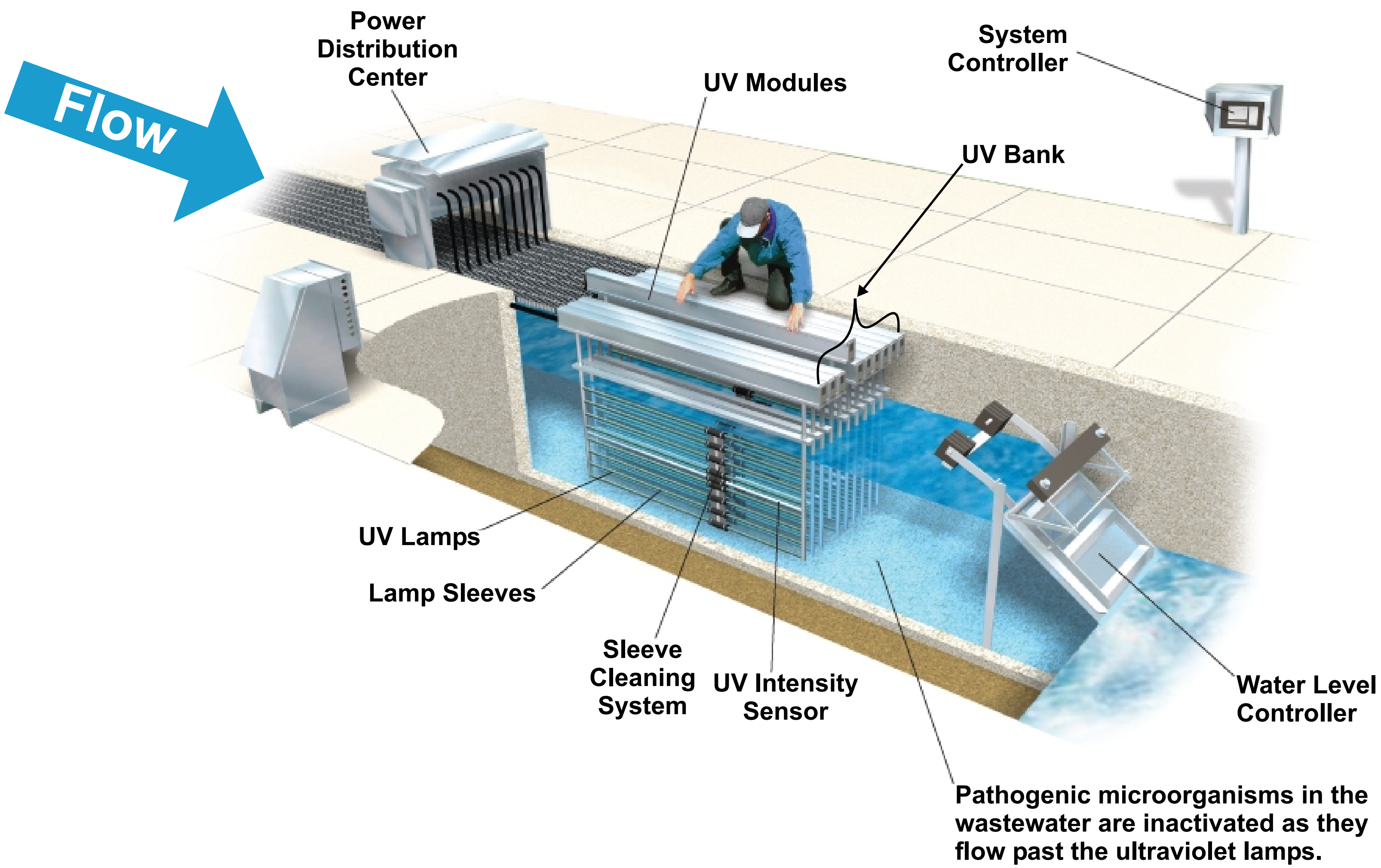
9.5.2.2 <u>Disadvantages</u>

- Not effective on EDCs.
- Higher cost than chlorine-based disinfection.
- Performance can be negatively affected by the presence of particle-associated organisms: It is expected that the RWQCP tertiary effluent has low turbidity and small particles. Therefore, UV is expected to be effective at the designed dose for this project.

9.5.3 Ozone

Ozone disinfects by oxidizing the cell walls of the microorganisms, causing them to disintegrate. This is a different mechanism from chlorine, which diffuses though the cell wall, making the cell susceptible to enzymatic attack. For this reason, ozone disinfects more effectively and much faster. Ozone was originally used in potable water treatment. The use of ozone for wastewater disinfection has not increased comparably to its use in drinking water disinfection, due to its high cost for a high dose. A typical ozone process schematic is shown on Figure 9.2.

Because recent research has shown that EDCs may cause gender deformities in fish around ocean outfalls and surface water discharges, it is predicted that EDCs will be regulated in the future.



Note:
UV systems usually consist of multiple banks in series per channel.

OPEN-CHANNEL UV SYSTEM: TROJAN UV3000PLUS™

FIGURE 9.1

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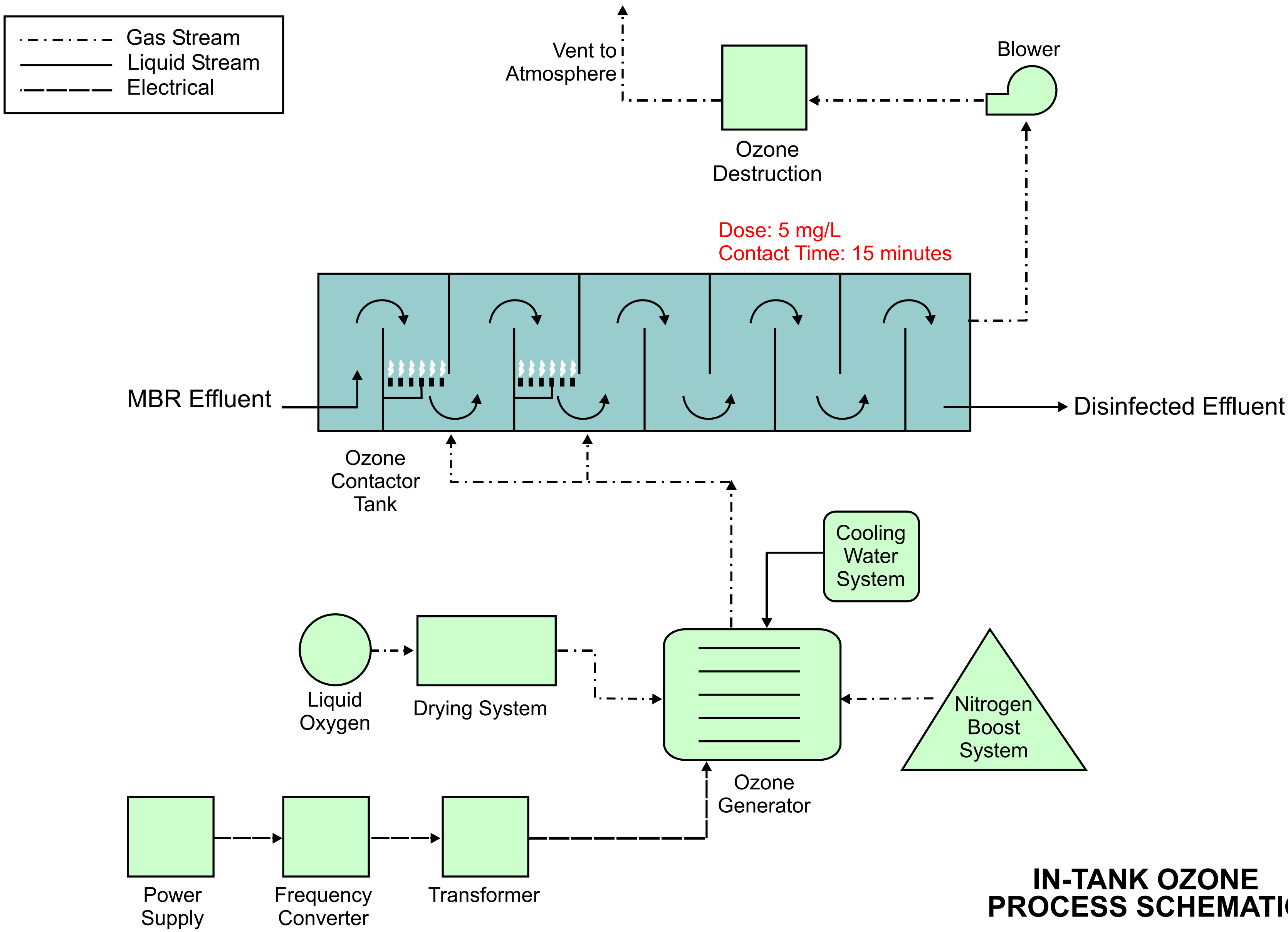


IN-TANK OZONE PROCESS SCHEMATIC

FIGURE 9.2

Research also shows that ozone is the most effective method to destroy EDCs compared to NaOCl and UV. The advantages and disadvantages of ozone disinfection are as follows:

9.5.3.1 Advantages

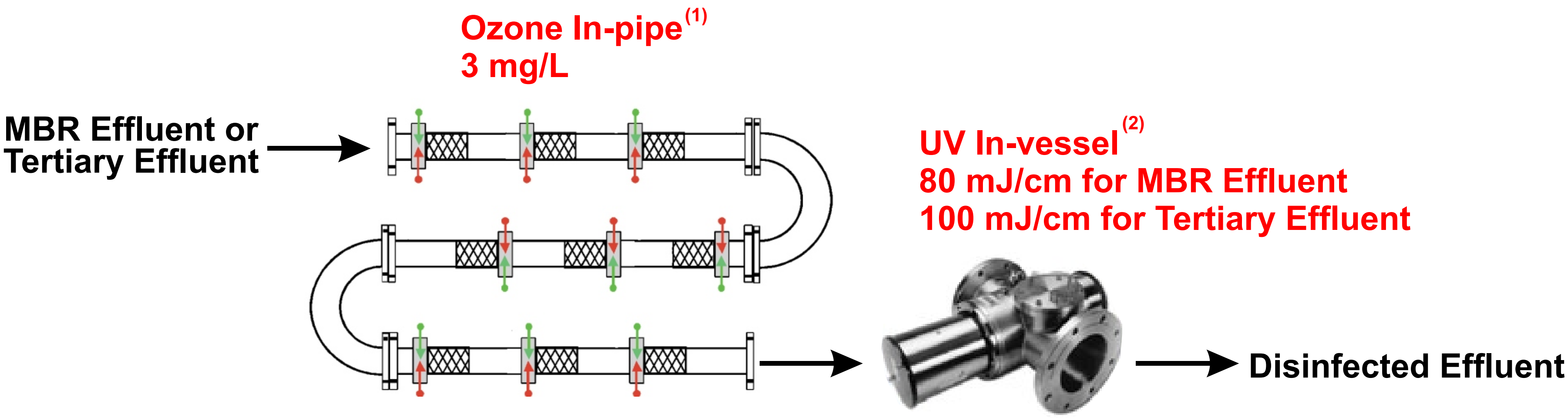
- Effective on bacteria, viruses, and micro-pollutants.
- Strong oxidant: Eliminates color, odor, and taste by oxidizing organic and inorganic matter (primarily potable water advantages).
- Increases the dissolved oxygen content of the effluent for river discharges.

9.5.3.2 Disadvantages

- Currently it is not approved by the CDHS as an accepted disinfection technology for the production of recycled water.
- High cost is related to the high dose and low efficiency of ozone generation equipment. Therefore, it is not cost effective without MBRs upstream.
- Possibility of bromate/bromine formation at high ozone doses (higher than 10 mg/L). Therefore, it is not applicable for conventional tertiary effluent, which requires high doses.
- Complexity of the ozone system: Ozone has to be generated on-site and the equipment includes an ozone generator, power supply unit, ozone dissolution system, ozone contactor, ozone destruction unit, nitrogen boosting system, cooling unit, Liquid Oxygen (LOX) storage, LOX filters, dryers and vaporizers, valves, and controls.
- Ozone is corrosive and toxic.
- Off-gas requires destruction.
- Organic disinfection by-products may be formed in the process, such as aldehydes, ketones, and acetaldehydes.

9.5.4 Ozone and Ultraviolet

Because low dose ozone can increase UV transmittance, the disinfection costs using low dose ozone followed by UV are potentially equivalent to UV only costs. Additionally, because of the concern of EDCs and the infeasibility of ozone as a disinfection method for non-MBR applications, a combined ozone and UV process, as shown on Figure 9.3, is evaluated for the Master Plan. To obtain a higher ozone contact efficiency and improve hydraulics, an in-pipe ozone contactor (Applied Process Technology Inc., Pleasant Hill, California) is used for this alternative. In addition, an in-vessel UV reactor is used in this process for better dose distribution.



Notes:

1. Ozone in-pipe contactor (Applied Process Technology, Pleasant Hill, CA) provides 1 minute contact time for mixing.
2. UV dose includes fouling and aging factors.

OZONE IN-PIPE AND UV IN-VESSEL PROCESS SCHEMATIC

FIGURE 9.3

The advantages and disadvantages of the combination of ozone and UV disinfection are as follows:

9.5.4.1 Advantages

- Low dose ozone will increase UV transmittance and provide partial disinfection and micro-pollutant destruction with less possibility of bromate/bromine formation. Shorter ozone contact time.
- No requirement for residual ozone destruction.
- An Advanced Oxidation Process (AOP) in which secondary oxidants are formed to oxidize organic and inorganic compounds including EDCs.

9.5.4.2 Disadvantages

- No experience in a wastewater application.
- The combined low dose ozone and UV process has currently not been approved by CDHS for water recycling applications.

9.6 NON-ECONOMIC COMPARISON OF ALTERNATIVES

A non-economic comparison of the alternatives is summarized in Table 9.3.

Table 9.3 Non-Economic Comparisons of Disinfection Alternatives
Wastewater Collection and Treatment Facilities Integrated Master Plan
City of Riverside

	NaOCl	UV	Ozone	Ozone+UV
Microorganism Inactivation	0	+	0	+
EDC Destruction	0	–	+	+
Contact Time	–	+	+	+
Disinfection By-Products	–	+	0	+
TDS	–	+	+	+
Safety Concerns	–	+	–	–
Operating Experience	+	0	–	–
Ease of Operation	+	0	–	–
Ease of Maintenance	+	–	–	–
Disinfection Residual	Yes	No	No	No

Ratings:
+ = Positive comparative characteristic.
– = Negative comparative characteristic.
0 = Neutral comparative characteristic.

9.7 LIFE-CYCLE COST

Life-cycle costs for the alternatives are shown in Tables 9.4 through 9.6.

Table 9.4 presents a comparison of the alternatives for disinfection facilities sized for 8 mgd. In this comparison, all of the disinfection alternatives are assumed for conventional tertiary effluent. In addition, in this comparison, the existing NaOCl disinfection system would continue to be used for 44 mgd and an additional 8 mgd of disinfection would be provided by one of the three alternatives for disinfection. This would increase the total disinfection system capacity from 44 mgd to 52 mgd.

Table 9.4 Life-Cycle Costs of Disinfection Alternatives: 8-mgd Conventional Effluent
Wastewater Collection and Treatment Facilities Integrated Master Plan
City of Riverside

Disinfection	NaOCl[1]	UV	Ozone+UV[2]
Total Project Cost	$4,070,000	$10,100,000	$22,230,000
Yearly O&M Cost	$151,000	$228,000	$381,000
Life-Cycle Cost[3]	**$6,670,000**	**$14,010,000**	**$28,770,000**

Notes:
(1) Yearly operation and maintenance (O&M) cost and life-cycle cost for NaOCl disinfection include the costs for dechlorination with sodium bisulfite.
(2) Cost based on UV dose of 100 mJ/cm^2 for conventional tertiary effluent. The dose, and thus the cost, may be lowered upon the completion of pilot testing.
(3) As present value, assuming life-cycle period of 19 years, discount rate of 6 percent, and escalation rate of 6 percent for the first 5 years and 4 percent thereafter.

Table 9.5 presents a comparison of the alternatives for disinfection facilities sized for 52 mgd. Similar to the comparison in Table 9.5, all of the disinfection alternatives in this comparison are assumed for conventional tertiary effluent. In this comparison, for the NaOCl alternative, the existing NaOCl disinfection system would continue to be used for 44 mgd and an additional 8-mgd CCB would provide the remaining disinfection capacity. For the UV and ozone alternatives, new facilities with a capacity of 52 mgd would be required, because either of these alternatives would replace the existing NaOCl facilities if selected.

Table 9.5 Life-Cycle Costs of Disinfection Alternatives: 52-mgd Conventional Effluent
Wastewater Collection and Treatment Facilities Integrated Master Plan
City of Riverside

Disinfection	NaOCl[1]	UV	Ozone+UV[2]
Total Project Cost	$4,070,000	$47,000,000	$70,410,000
Yearly O&M Cost	$980,000	$1,279,000	$1,579,000

Table 9.5 Life-Cycle Costs of Disinfection Alternatives: 52-mgd Conventional Effluent
Wastewater Collection and Treatment Facilities Integrated Master Plan
City of Riverside

Disinfection	NaOCl[1]	UV	Ozone+UV[2]
Life-Cycle Cost[3]	**$20,900,000**	**$68,950,000**	**$97,520,000**

Notes:
(1) The project cost for NaOCl disinfection only includes the additional 8-mgd CCB. Yearly O&M cost and life-cycle cost include chlorination and dechlorination for both existing and new facilities for 52 mgd.
(2) Cost based on UV dose of 100 mJ/cm^2 for conventional tertiary effluent. The dose, and thus the cost, may be lowered upon the completion of pilot testing.
(3) As present value, assuming life-cycle period of 19 years, discount rate of 6 percent, and escalation rate of 6 percent for the first 5 years and 4 percent thereafter.

Table 9.6 also presents a comparison of the alternatives for disinfection facilities sized for 52 mgd. However, in this comparison, it is assumed that the disinfection alternatives will be for 20 mgd of conventional tertiary effluent and 32 mgd of MBR effluent. In this comparison, for the NaOCl alternative, the existing NaOCl disinfection system would continue to be used for 44 mgd and an additional 8-mgd CCB would provide the remaining disinfection capacity. For the UV and/or ozone alternatives, new facilities with a capacity of 52 mgd would be required, because either of these alternatives would replace the existing NaOCl facilities if selected. However, there are several different combinations of UV and ozone treatment that can be applied to the 52 mgd, depending upon whether the influent to the disinfection system is from conventional tertiary or MBR systems. These combinations follow the general rule that ozone is only used in series with UV for disinfection of conventional tertiary effluent, but can be used by itself for disinfection of MBR effluent. As described previously, this is due to the potential for bromate/bromine formation when high doses of ozone are applied to conventional tertiary effluent, and it is not a problem for MBR effluent because lower ozone doses are required.

At the project meeting on December 20, 2006, it was decided to continue the use of NaOCl as the only disinfection method until regulatory changes require a method to remove additional pollutants, such as EDCs. The decision was based on the high cost to implement ozone or ozone plus UV. Under the current regulatory conditions, minimal additional expenditures would be required to continue using NaOCl. In addition, when regulatory changes do require an advanced disinfection method, it will likely be ozone or a combination of ozone and UV. The final method would be determined during preliminary design. Alternative treatment scenarios for the MPM™ will be established that include ozone and a combination of ozone and UV.

It was also decided that the City should perform tracer tests to determine the actual requirement for additional chlorine contact basins.

Table 9.6 Life-Cycle Costs of Disinfection Alternatives: 20-mgd Conventional Effluent and 32-mgd MBR Effluent
Wastewater Collection and Treatment Facilities Integrated Master Plan
City of Riverside

Disinfection for Conventional	**NaOCl[1]**	**UV**	**Ozone +UV[2]**	**UV**	**Ozone +UV[2,3]**	**Ozone +UV[2]**
Disinfection for MBR	**NaOCl[1]**	**UV**	**UV**	**Ozone**	**Ozone[3]**	**Ozone +UV[4]**
Total Project Cost	$4,070,000	$34,000,000	$52,540,000	$53,980,000	$72,520,000	$64,370,000
Yearly O&M Cost	$980,000	$880,000	$1,106,000	$1,677,000	$1,902,000	$1,347,000
Life-Cycle Cost[5]	**$20,900,000**	**$49,100,000**	**$71,530,000**	**$82,760,000**	**$105,180,000**	**$87,500,000**

Notes:

(1) The project cost for NaOCl disinfection only includes the additional 8-mgd CCB. Yearly O&M cost and life-cycle costs include chlorination and dechlorination for both existing and new facilities for 52 mgd.

(2) Cost based on UV dose of 100 mJ/cm^2 for conventional tertiary effluent. The dose, and thus the cost, may be lowered upon the completion of pilot testing.

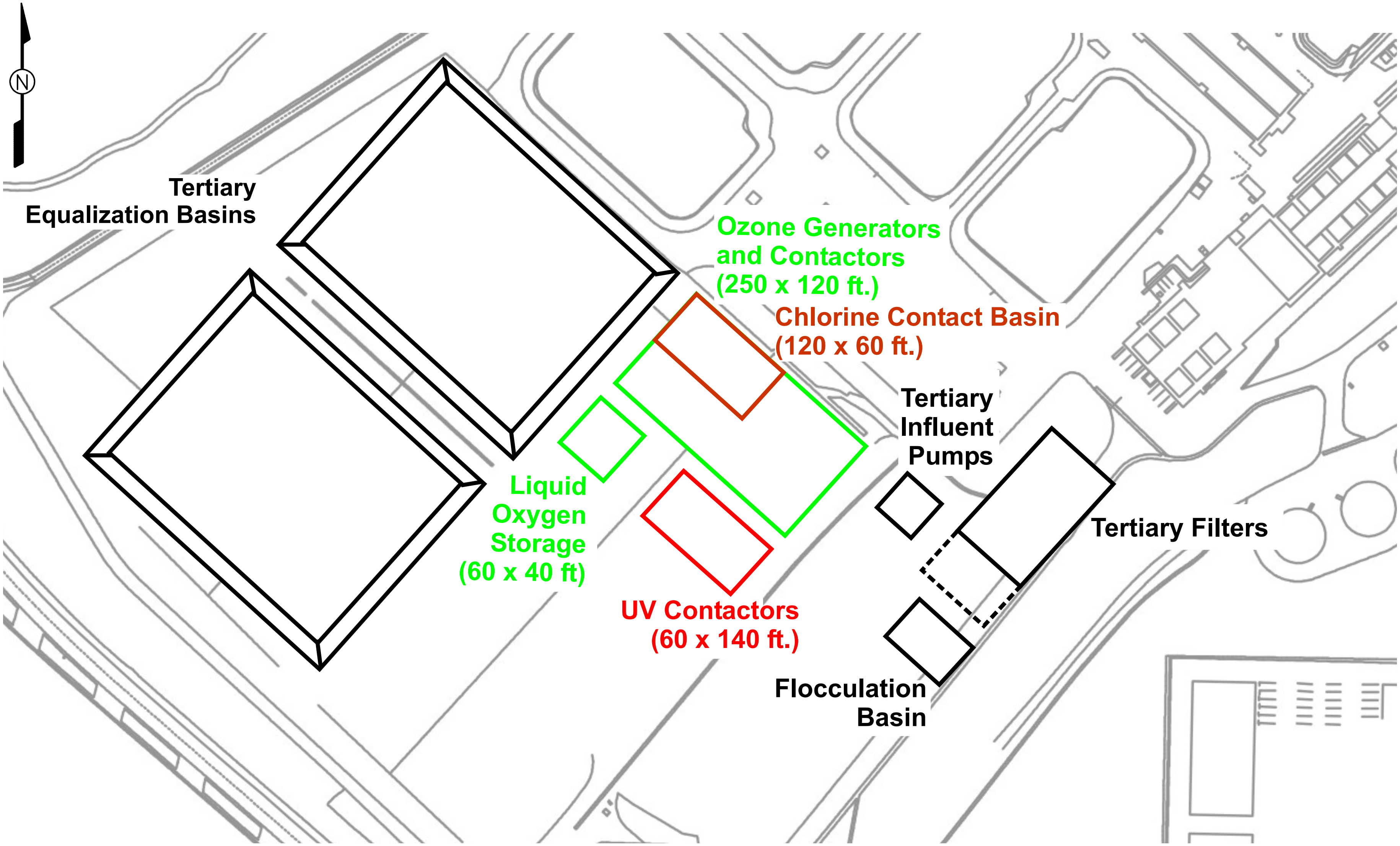
(3) Cost based on in-pipe ozone contactor for 32 mgd, and in-tank ozone contactor for 20 mgd. In-tank ozone contactor can be used for both streams to lower the cost if hydraulically feasible.

(4) Cost based on UV dose of 80 mJ/cm^2 for MBR effluent. The dose, and thus the cost, may be lowered upon the completion of pilot testing.

(5) As present value, assuming life-cycle period of 19 years, discount rate of 6 percent, and escalation rate of 6 percent for the first 5 years and 4 percent thereafter. Includes chlorination and dechlorination O&M costs for the existing 44-mgd facilities.

9.8 DISINFECTION FACILITY LAYOUT

Figure 9.4 shows the proposed layout of the UV and ozone facilities as an alternative treatment strategy in the MPM^{TM}. After the tracer test, if it is determined that an additional chlorine contact basin is needed instead of advanced disinfection, it will be located where the ozone facilities are shown on Figure 9.4.



NEW DISINFECTION FACILITIES LAYOUT

FIGURE 9.4

carollo
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WASTEWATER COLLECTION AND TREATMENT
FACILITIES INTEGRATED MASTER PLAN

CITY OF RIVERSIDE